

*AMS Short Course on the Fundamentals of Boundary Layer Wind and
Temperature Profiling Using Radar and Acoustic Techniques
February 8 & 9, 2003*

Boundary Layer Profilers for Regulatory Applications (An Air Quality Perspective)

Kevin R. Durkee

Satoru J. Mitsutomi, Ph.D.

**South Coast Air Quality Management District
Diamond Bar, California**



Alex Barnett

**PCR Services Corporation
Santa Monica, California**

Overview

- Air Quality Measurement Programs
- Examples of regulatory applications for BL profilers
- Upper-air measurement incentives from the US EPA PAMS program
- Regulatory profiler data management issues and recommendations

Air Quality Measurement Programs Applying Boundary Layer Profiler Data

- National Programs
- Multi-State & Large Regional Studies
- Regional & Local Programs
- Special Interests & Consortia

Air Quality Measurement Programs Applying Boundary Layer Profiler Data

■ National Programs

- Multi-State & Large Regional Studies
- Regional & Local Programs
- Special Interests & Consortia

■ US Environmental Protection Agency (EPA) has supported boundary layer profiling work for many years

- Sodars, RWP/RASS, lidars, microwave radiometers, balloons, aircraft

National Programs

US EPA PAMS Program

- Main focus is monitoring of photochemical ozone precursors
- Approximately 24 areas designated Serious Non-Attainment of the federal 1-hour ozone standard
- Approximately 60 Volatile Organic Compounds (VOCs) analyzed
 - Not an Air Toxics monitoring program, but there are many target compounds in common

National Programs

PAMS Overview

- ~80 PAMS Air Monitoring Stations in 22 Networks
- ~24 Ozone Non-Attainment Areas
- 14 Main Target Parameters
 - total non-methane hydrocarbons (TNMHC) and 13 volatile organic compounds (VOCs) & Carbonyls
- EPA grants State, local, and consolidated environmental agencies approximately \$3 million annually to monitor, characterize and analyze PAMS data
 - including upper air portion

National Programs

PAMS Goals

- Contribute to overall understanding of ozone formation and transport
- Objectives:
 - Verification of control strategy effectiveness
 - Emission inventory review & refinement
 - Emission-based model support
 - Ozone/Precursor trend analysis
 - Exposure modeling & analysis

PAMS Target Volatile Organic Compounds (1996)

AIRS NO.	PAMS Manual Abbreviation	Compound	Class
43206	acety	Acetylene	Olefin
43203	ethyl	Ethylene	Olefin
43202	ethan	Ethane	Paraffin
43205	prpyl	Propylene	Olefin
43204	propa	Propane	Paraffin
43214	isbta	Isobutane	Paraffin
43280	1bute	1-Butene	Olefin
43212	nbuta	n-Butane	Paraffin
43216	t2bte	trans-2-Butene	Olefin
43217	c2bte	cis-2-Butene	Olefin
43221	ispna	isopentane	Paraffin
43224	1pnte	1-Pentene	Olefin
43220	npnta	n-Pentane	Paraffin
43243	ispre	Isoprene	Olefin
43226	t2pne	trans-2-Pentene	Olefin
43227	c2pne	cis-2-Pentene	Olefin
43244	22dmb	2,2-Dimethylbutane	Paraffin
43242	cypna	Cyclopentane	Paraffin
43284	23dmb	2,3-Dimethylbutane	Paraffin
43285	2mpna	2-Methylpentane	Paraffin
43230	3mpna	3-Methylpentane	Paraffin
43246	2m1pe	2-Methyl-1-Pentene	Olefin
43231	nhexa	n-Hexane	Paraffin
43262	mcpna	Methylcyclopentane	Paraffin
43247	24dmp	2,4-Dimethylpentane	Paraffin
45201	benz	Benzene	Aromatic
43248	cyhxa	Cyclohexane	Paraffin
43263	2mhxa	2-Methylhexane	Paraffin
43291	23dmp	2,3-Dimethylpentane	Paraffin
43249	3mhxa	3-Methylhexane	Paraffin
43250	224tmp	2,2,4-Trimethylpentane	Paraffin
43232	nhept	n-heptane	Paraffin

AIRS NO.	PAMS Manual Abbreviation	Compound	Class
43261	mcyhx	Methylcyclohexane	Paraffin
43252	234tmp	2,3,4-Trimethylpentane	Paraffin
45202	tolu	Toluene	Aromatic
43960	2mhhep	2-Methylheptane	Paraffin
43253	3mhhep	3-Methylheptane	Paraffin
43233	noct	n-Octane	Paraffin
45203	ebenz	Ethylbenzene	Aromatic
45109	m/pxy	m/p-Xylene	Aromatic
45220	stry	Styrene	Aromatic
45204	oxyl	o-Xylene	Aromatic
43235	nnon	n-Nonane	Paraffin
45210	ispbz	Isopropylbenzene	Aromatic
45209	npbz	n-Propylbenzene	Aromatic
45208	124tmb	1,2,4-Trimethylbenzene	Aromatic
45207	135tmb	1,3,5-Trimethylbenzene	Aromatic
45211	oetol	o-Ethyltoluene	Aromatic
45212	metol	m-Ethyltoluene	Aromatic
45213	petol	p-Ethyltoluene	Aromatic
45218	mdeben	m-Diethylbenzene	Aromatic
45219	pdeben	p-Diethylbenzene	Aromatic
45225	123tmb	1,2,3-Trimethylbenzene	Aromatic
43238	ndec	n-Decane	Paraffin
43954	nundc	n-Undecane	Paraffin
43502	form	Formaldehyde	Carbonyl
43551	acet	Acetone	Carbonyl
43503	aceta	Acetaldehyde	Carbonyl
43102	NMOC	Total NMOC	

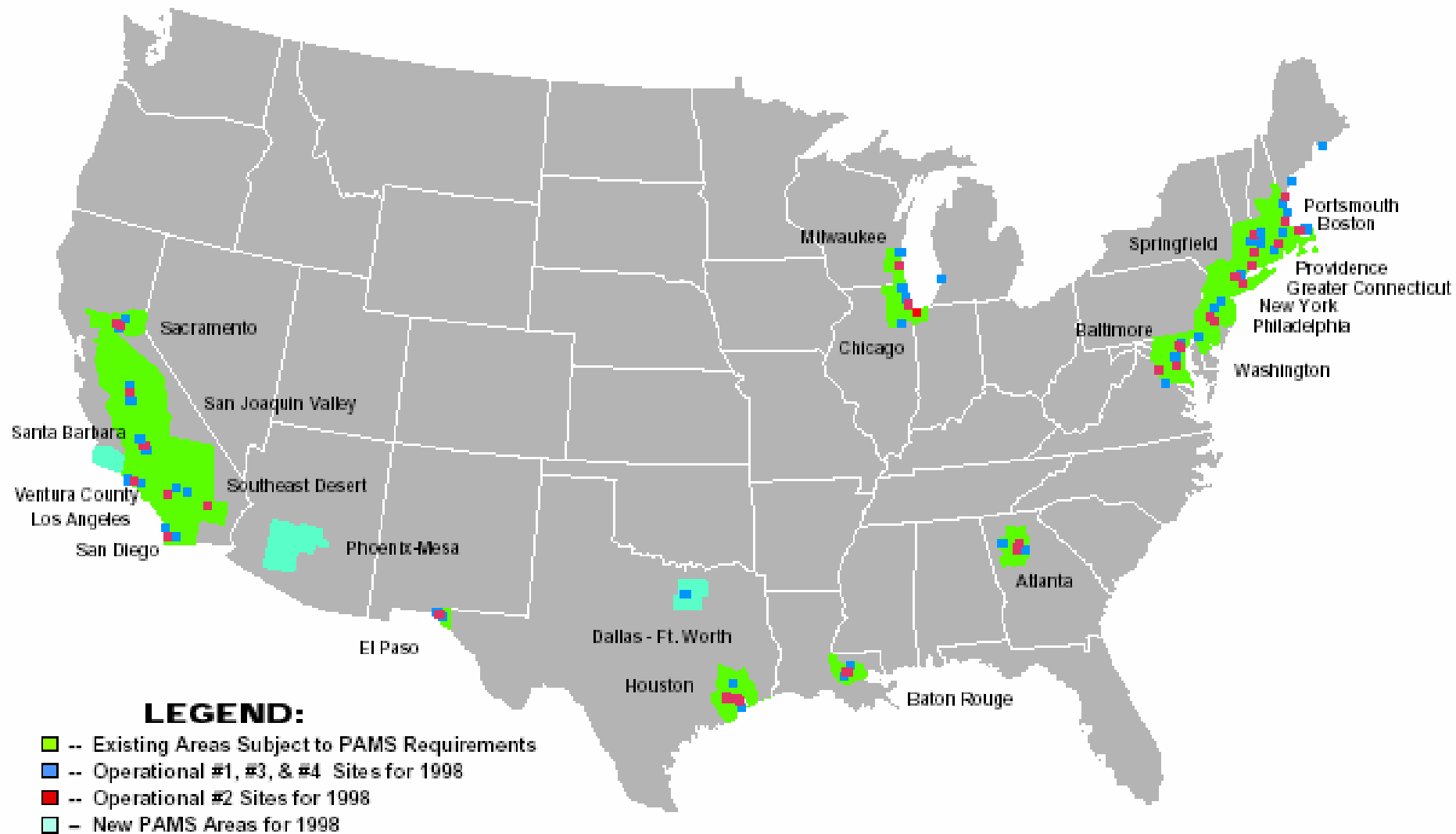
PAMS Non- Attainment Areas

Atlanta, GA	Serious
Baltimore, MD	Severe
Baton Rouge, LA	Serious
Boston-Lawrence-Worcester, MA-NH	Serious
Dallas-Fort Worth, TX	Serious
El Paso, TX	Serious
Greater Connecticut, CT	Serious
Houston-Galveston-Brazoria, TX	Severe
South Coast-SEDAB: Greater Los Angeles & SEDAB, CA ²	Extreme
Lake Michigan: Chicago, IL & IN & Milwaukee-Racine, WI ¹	Severe
New York-New Jersey-Long Island, NY-NJ-CT	Severe
Phoenix, AZ	Serious
Philadelphia-Wilmington-Trenton, PA-NJ-DE-MD	Severe
Portsmouth-Dover-Rochester, NH-ME	Serious
Providence-Pawtucket-Fall River, RI-MA	Serious
Sacramento, CA	Severe
San Diego, CA	Serious
San Joaquin Valley, CA	Serious
Santa Barbara-Santa Maria-Lompoc, CA	Serious
Springfield, MA	Serious
Ventura County, CA	Severe
Washington, DC-MD-VA	Serious

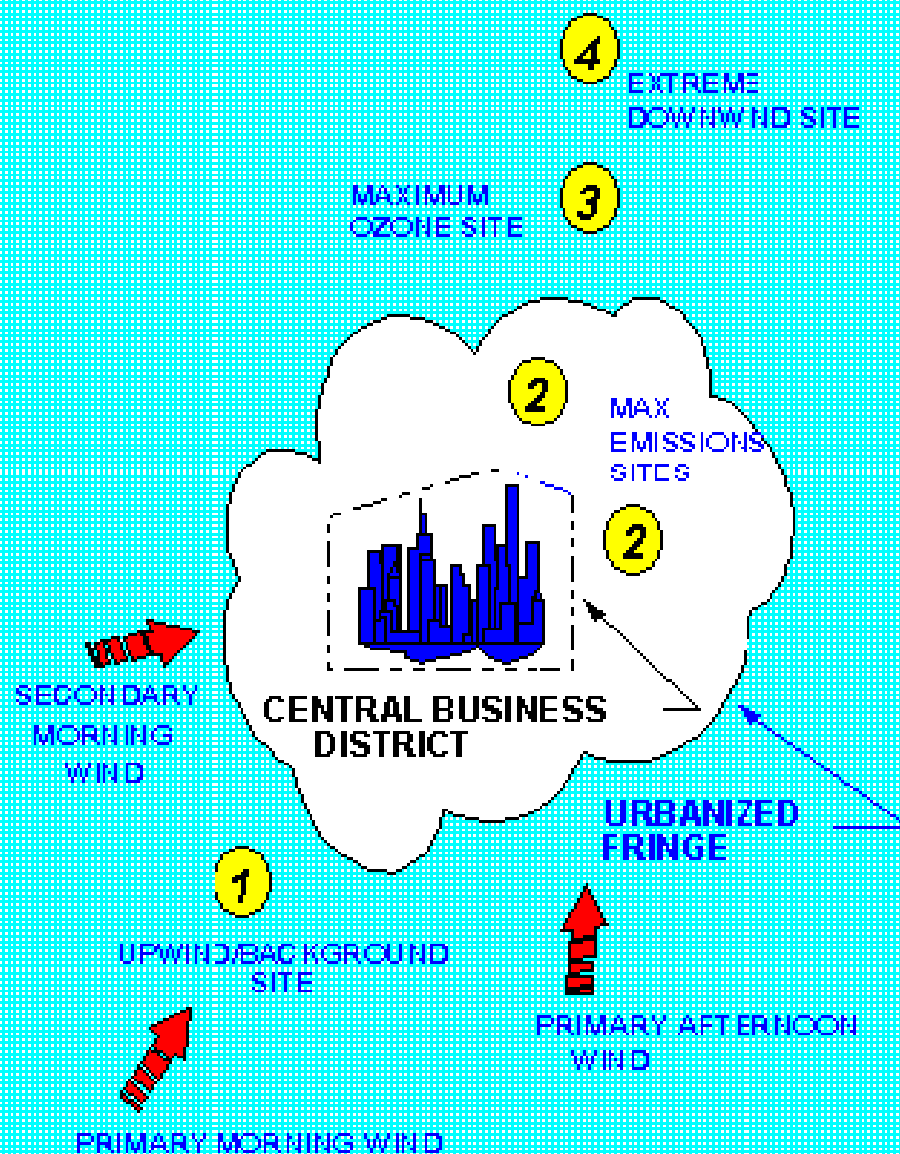
1) Chicago and Milwaukee are combined into one PAMS area referred to as Lake Michigan.

2) Los Angeles-South Coast and SE Desert Modified AQMA are combined into one PAMS area referred to as South Coast-SEDAB

Operating PAMS Sites, 1998



PAMS NETWORK DESIGN



National Programs

PAMS Upper Air Monitoring Requirement

Clean Air Act Requirement

(Title 40, Chapter I, Part 58, Appendix D, Section 4.6 PAMS Meteorological Monitoring)

- Upper air meteorological monitoring is required for each PAMS area
- The location should be representative of the upper air data in the nonattainment area

PAMS Technical Assistance Documentation

- The optimal design for a given PAMS region is expected to be some combination of remote sensing and conventional atmospheric soundings

PAMS Upper Air Data Objectives

- PAMS requirements
 - one upper-air station/network with a minimum of four soundings/day of winds and temperature
- Support Trajectory Analyses
 - For source apportionment & transport analyses
- Help Identify Critical Meteorological Phenomena
 - e.g., mixing height evolution, nocturnal jet, recirculation, sea-breeze, etc.
- Support Air Quality Modeling
 - Development & evaluation of 3-D wind, temperature & mixing height fields
- Support Ozone Episode Predictions
 - Inversion strength & breaking temperature
 - mixing height
 - Precursor & pollutant carryover, recirculation & transport potential

Air Quality Measurement Programs Applying Boundary Layer Profiler Data

- National Programs
- Multi-State & Large Regional Studies
- Regional & Local Programs
- Special Interests & Consortia

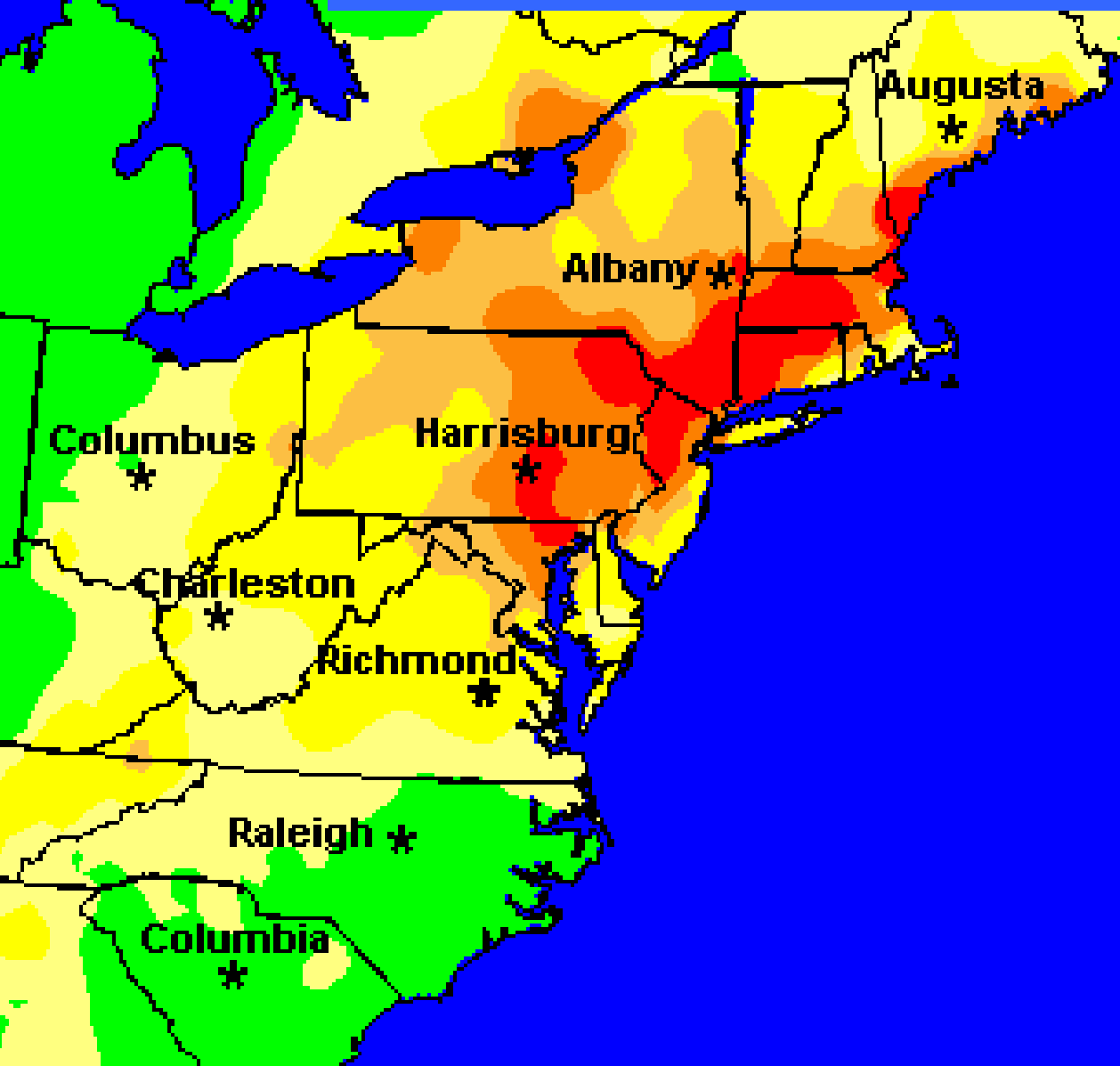
- Ozone Transport Affects Multi-State Regions

- Multi-State or Multi-Basin approach due to wide-ranging emissions or transport of pollutants & their precursors

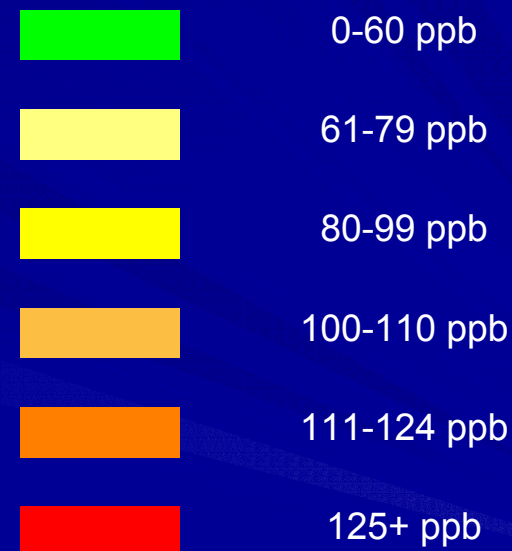
- Examples

- Mid-Atlantic Regional Air Management Association ([MARAMA](#))
- Northeast States for Coordinated Air Use Management ([NESAUM](#))

Mid-Atlantic & Northeast Corridor



1-hour Average Peak Concentration



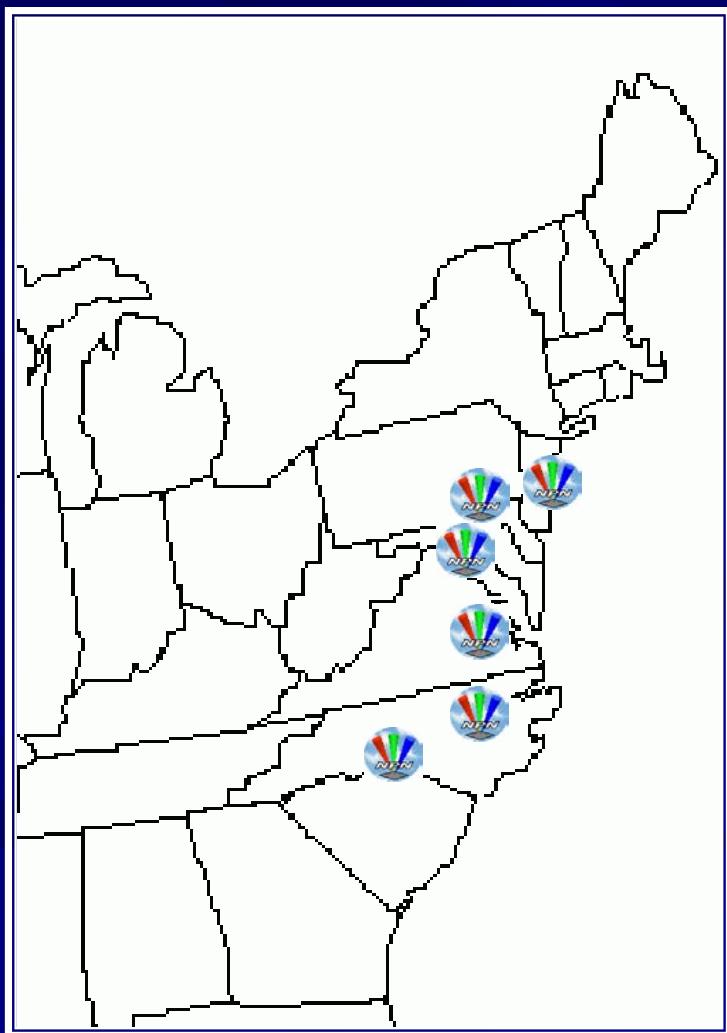
Source: US EPA AIRNOW
<http://www.epa.gov/airnow/>

August 14, 2002

Mid-Atlantic Profiler Network

(October 2001)

Source: MARAMA Profiler Work Group, <http://www.meteo.psu.edu/~wfryan/marama/ProfilerWorkGroup.htm>



Currently:

Rutgers, NJ

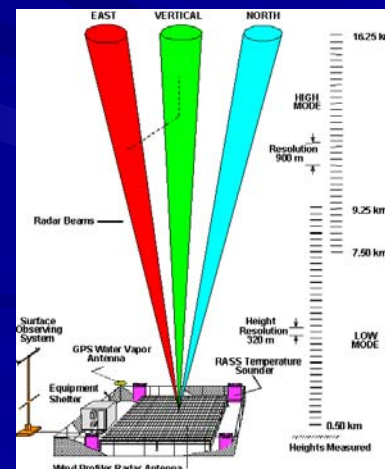
Philadelphia, PA

Fort Meade, MD

Richmond, VA

Raleigh, NC

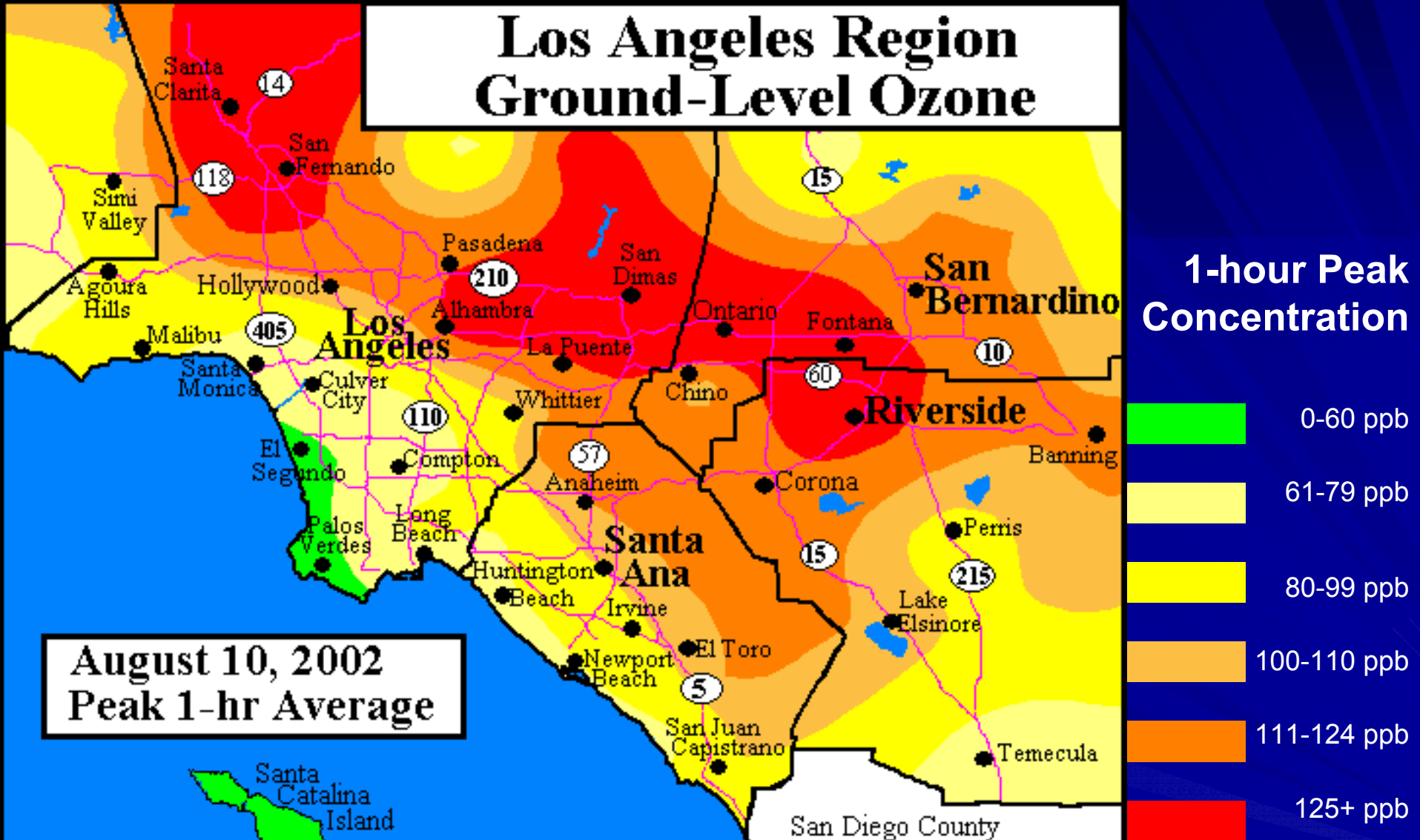
Charlotte, NC



Air Quality Measurement Programs Applying Boundary Layer Profiler Data

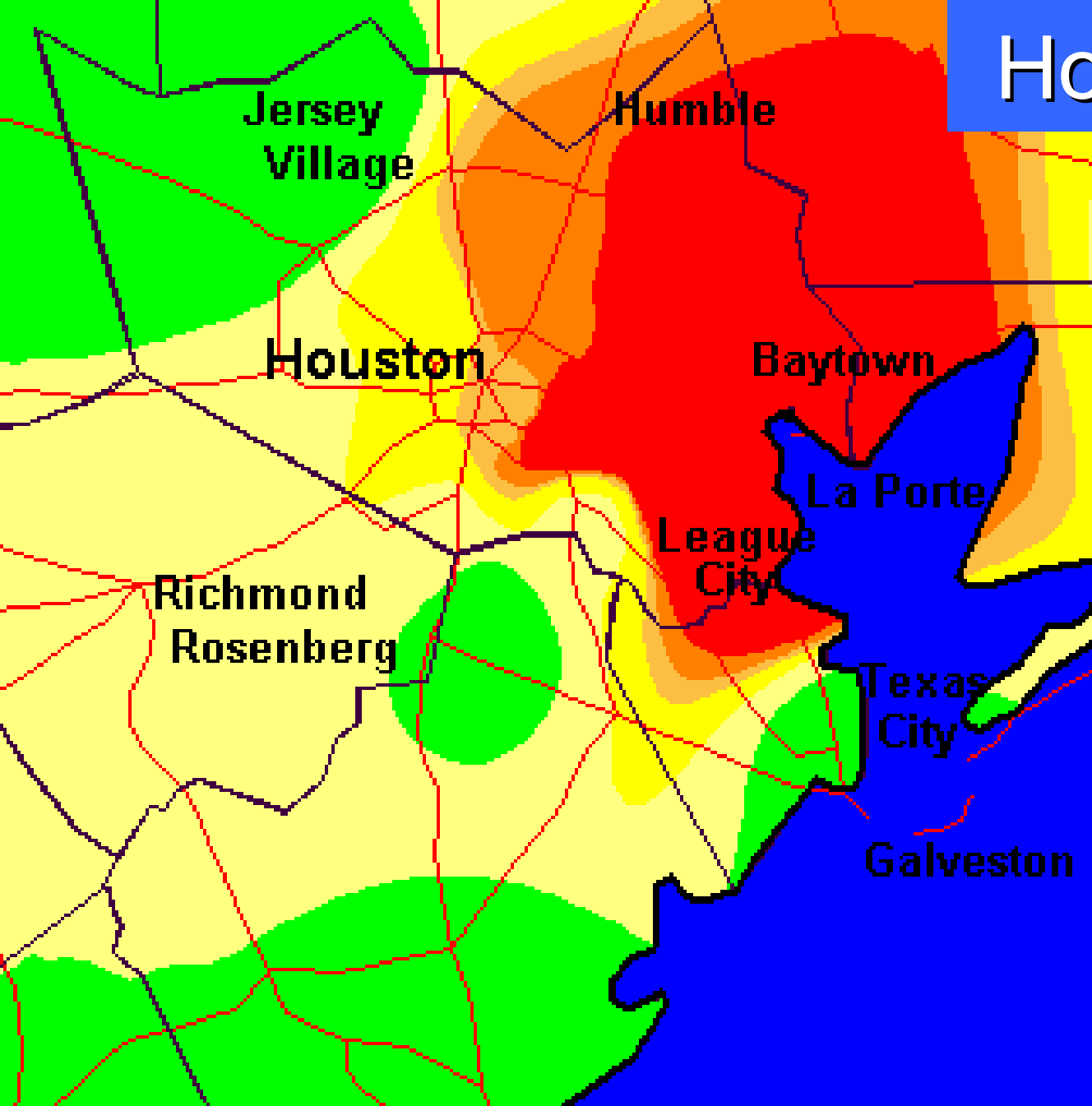
- National Programs
 - Multi-State & Large Regional Studies
 - Regional & Local Programs
 - Special Interests & Consortia
- Air Basin approach to Air Quality Management
 - e.g., South Coast Air Basin, Southeast Desert Air Basin, etc.
 - Geographic and meteorological boundaries *can* help confine air pollution
 - Controlled by local (county or regional) and state agencies
 - e.g., SCAQMD, SDCAPCD

Los Angeles Region Ground-Level Ozone

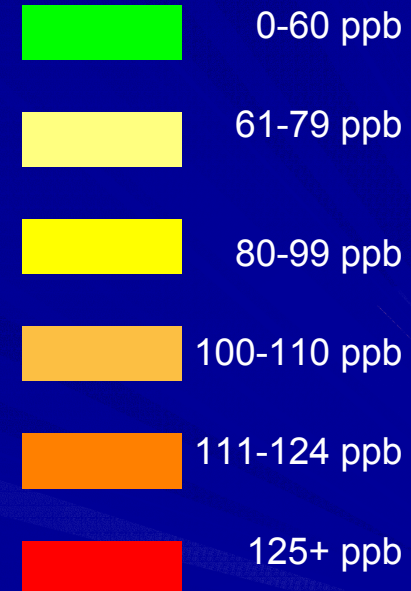


Source: US EPA AIRNOW
<http://www.epa.gov/airnow/>

Houston Area



1-hour Peak Concentration



July 23, 2002

Source: US EPA AIRNOW
<http://www.epa.gov/airnow/>

Air Quality Measurement Programs Applying Boundary Layer Profiler Data

- National Programs
 - Multi-State & Large Regional Studies
 - Regional & Local Programs
 - Special Interests & Consortia
- For Specific Problems or Multi-Disciplinary Projects
 - Examples
 - UC Davis/California Modeling Consortium
 - Northwest Regional Modeling Consortium
 - Puget Sound, WA
 - Owens Lake PM₁₀ Dust Control Project
 - Great Basin Unified APCD & Dept. of Water & Power

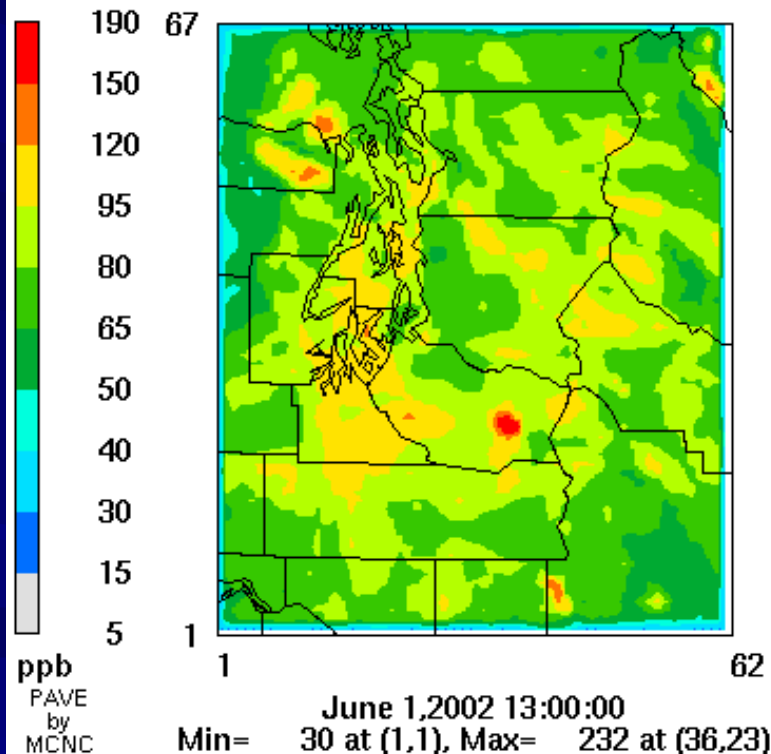
Washington State University AIRPACT

(Air Indicator Report for Public Awareness and Community Tracking)

Real-time Air Quality Forecasting System using MM5 & CALGRID

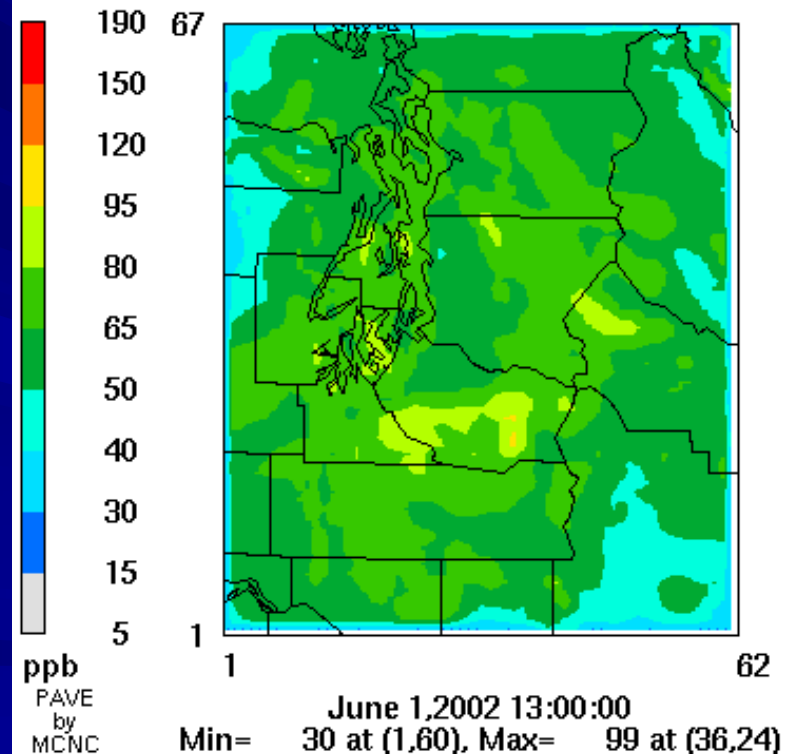
Maximum hourly avg O3 (in ppb)

as of 20030118 simulation,
since 20020601



Max 8-hr-avg O3, 11AM-12AM PST

as of 20030118 simulation,
since 20020601



Owens Lake, California Dust Management



Some Regulatory Applications Improved by Boundary Layer Profilers

- Air Quality
Forecasting
- Air Quality Modeling
- Source Evaluations
- Field Programs &
Case Analyses
- Other Environmental
Efforts

Some Regulatory Applications of Boundary Layer Profilers

→ Air Quality Forecasting

- Air Quality Modeling
- Source Evaluations
- Field Programs & Case Analyses
- Other Environmental Efforts

→ Forecasts for public health protection & episode awareness

- Criteria Pollutants (O_3 , PM_{10} , $PM_{2.5}$, CO , NO_2)

→ Routine (daily) or episodic forecasts

→ Specific forecasts for field study intensive operations

Air Quality Forecasting

- AQ forecasts typically consider
 - recent trends/current concentrations of smog & precursors
 - weather patterns & progs
- Surface Met Data Needs
 - winds (stagnation), pressure gradients, temperatures, humidity, solar insolation
- Upper-Air Data Needs
 - Inversion height and strength, mixing depth, breaking potential
 - Heating aloft (e.g., 850 mb Temps)
 - Winds - for transport & recirculation potential
 - Humidity profile (marine layer structure, PM chemistry)

Some Regulatory Applications of Boundary Layer Profilers

- Air Quality Forecasting
 - ➔ Air Quality Modeling
 - Source Evaluations
 - Field Programs & Case Analyses
 - Other Environmental Efforts
- ➔ Regional Modeling
 - ➔ Point-Source Modeling
 - ➔ Model Evaluation (Validation)
 - ➔ Trajectory & Pollutant Transport Assessment
 - Within Air Basin
 - Across Basin Boundaries
 - Long-Range

Upper Air Data in Regional Modeling

Air Quality Models

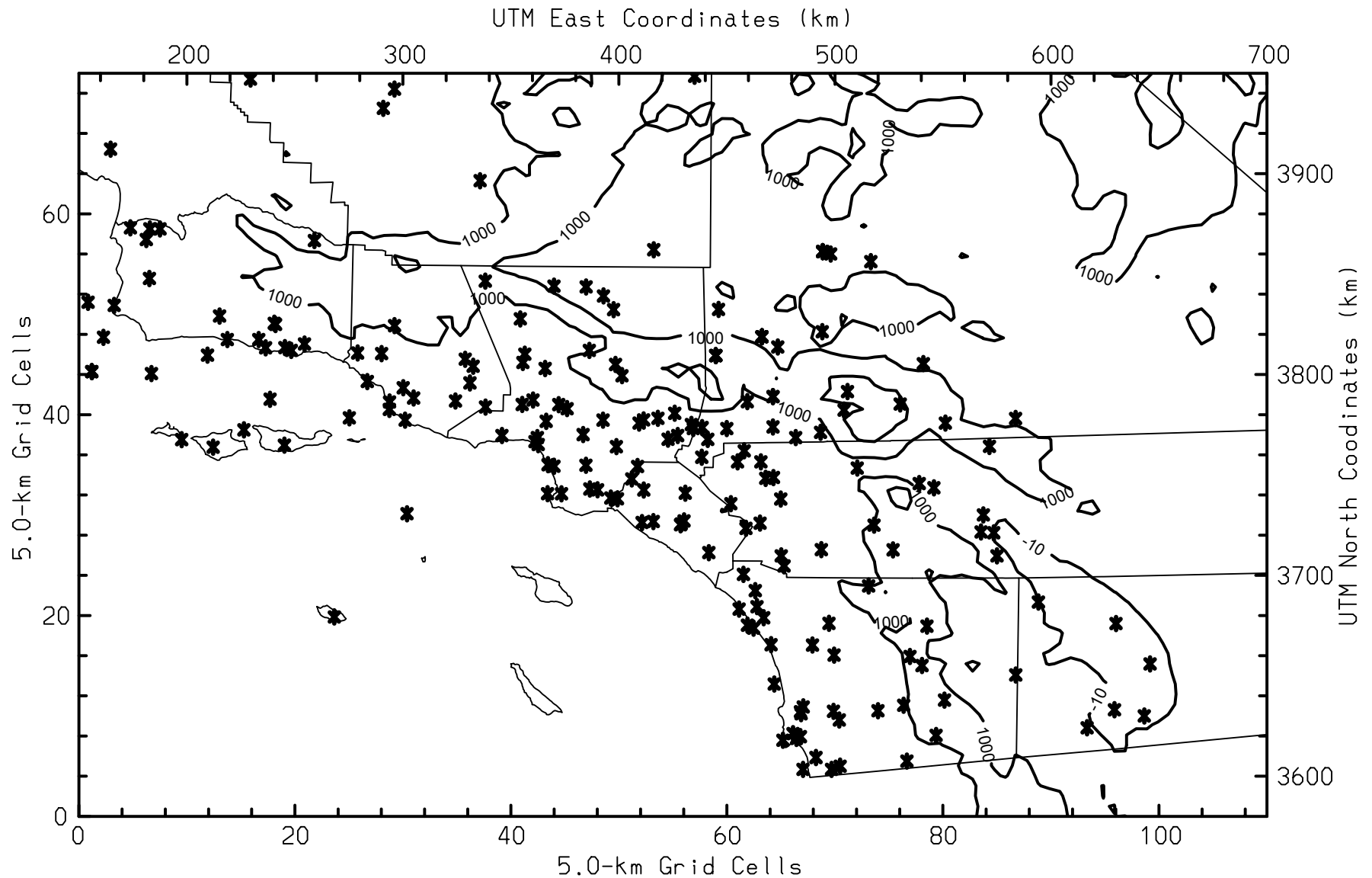
- Episodic AQ Modeling are used for Attainment Demonstration & Control Strategy Development
- Regional models simulate meteorology, emissions & smog chemistry for multi-day episodes
 - Can then evaluate effects of emissions changes due to growth and various control strategies
- AQ models require meteorological inputs from met models for each time step:
 - (3-D) gridded fields of winds, temperature, & humidity and (2-D) mixing height fields
- AQ model examples:
 - Urban Airshed Model, CALGRID, Models3

Upper Air Data in Regional Modeling

Meteorological Models

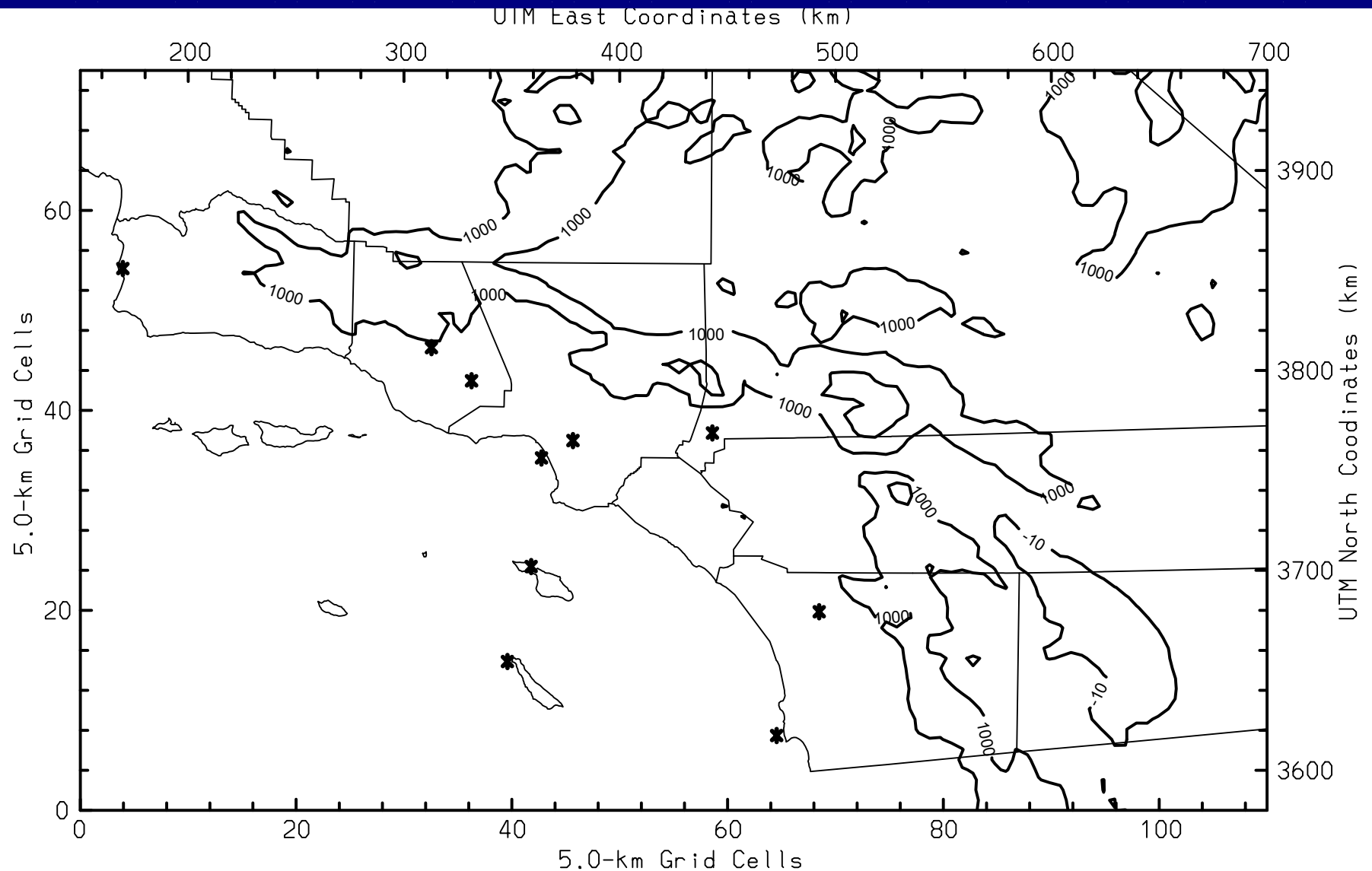
- Sufficient Upper Air data input critical for model performance
- UA data needed for evaluation (validation) & development of met & AQ models
- Met model examples:
 - CALMET, a diagnostic model
 - Pennsylvania State University/National Center for Atmospheric Research Mesoscale Meteorological Model (MM5), a prognostic model

Southern California Surface Data

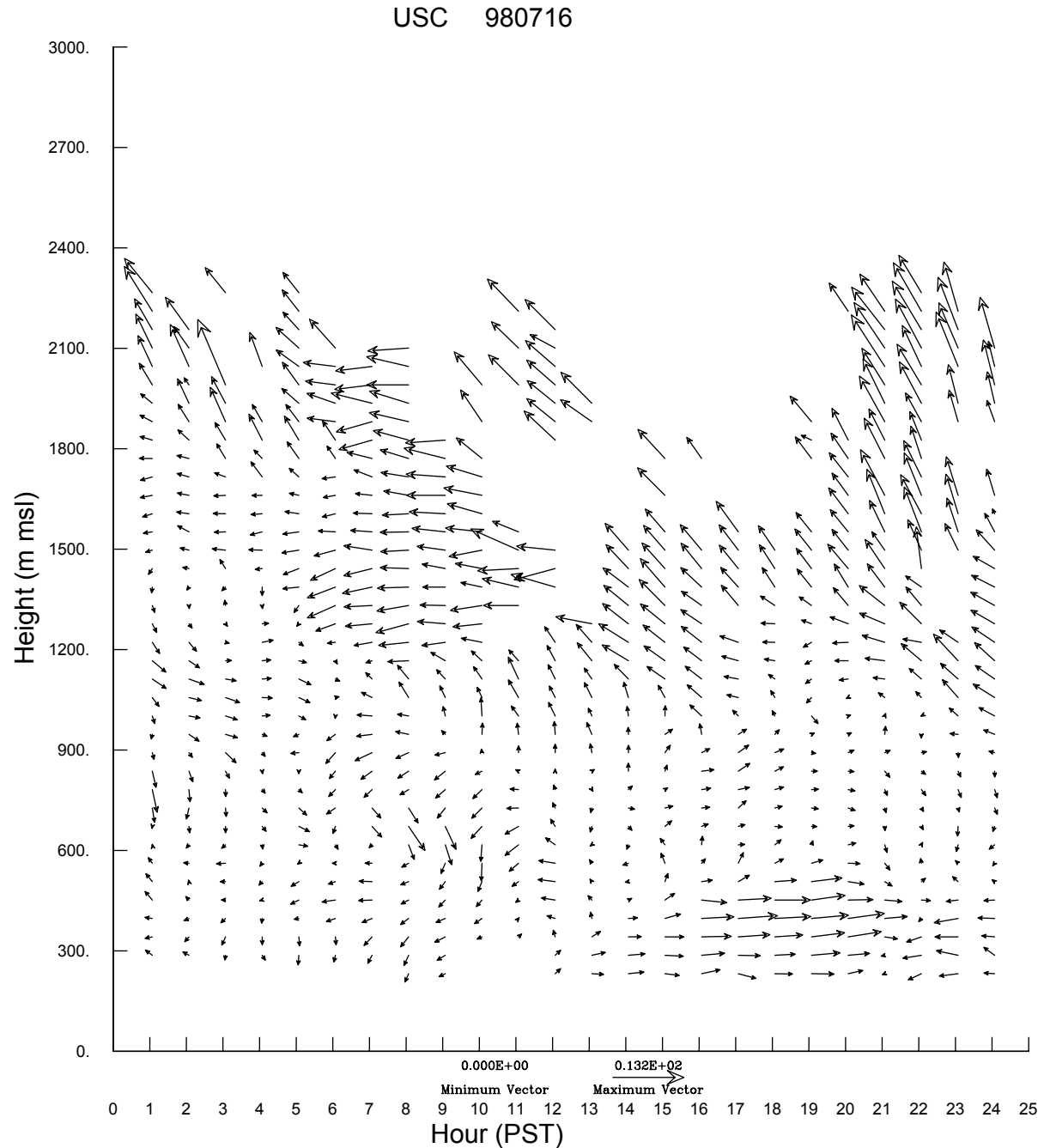


Southern California RWP/RASS Data

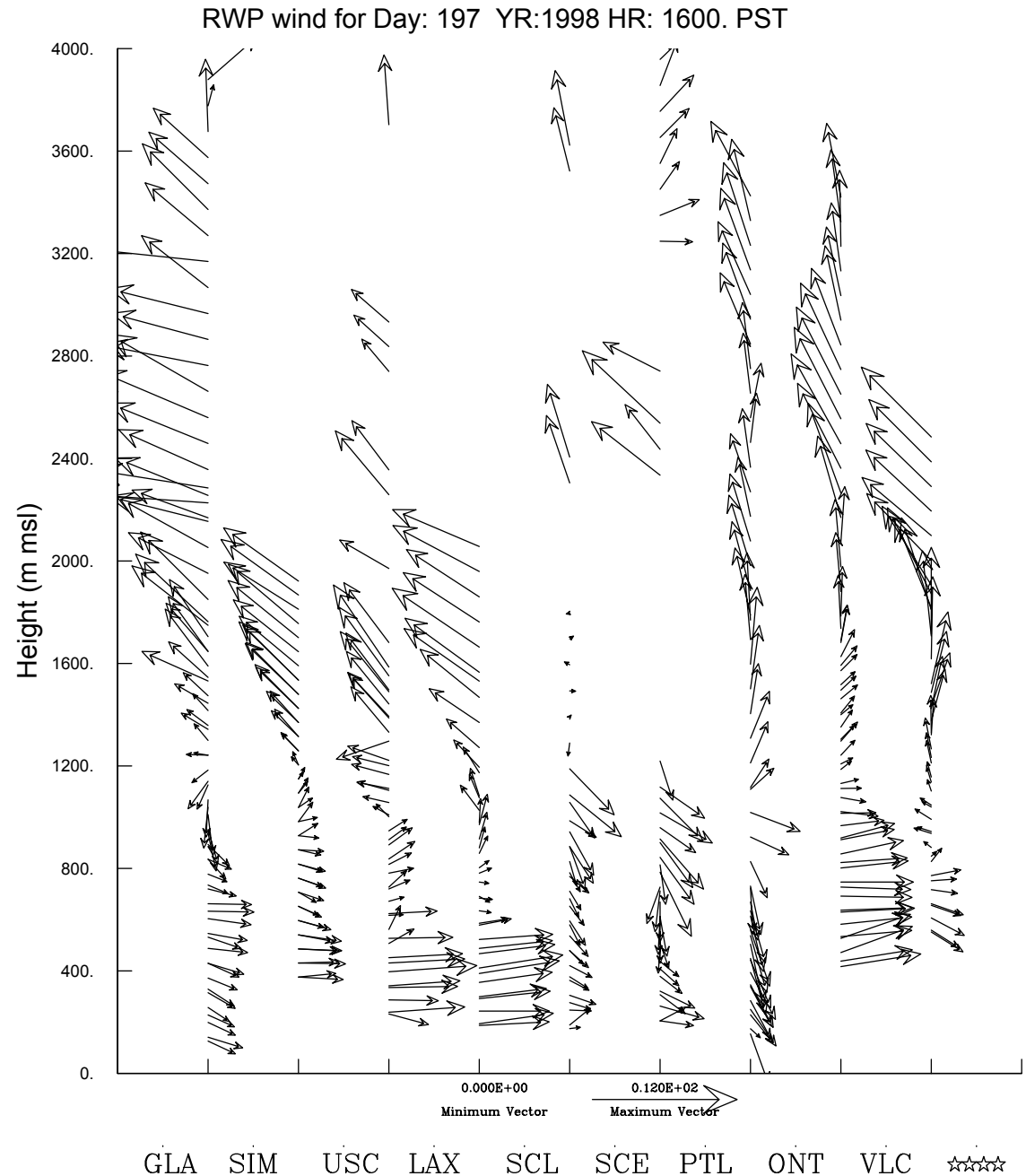
SCOS97 Modeling Domain



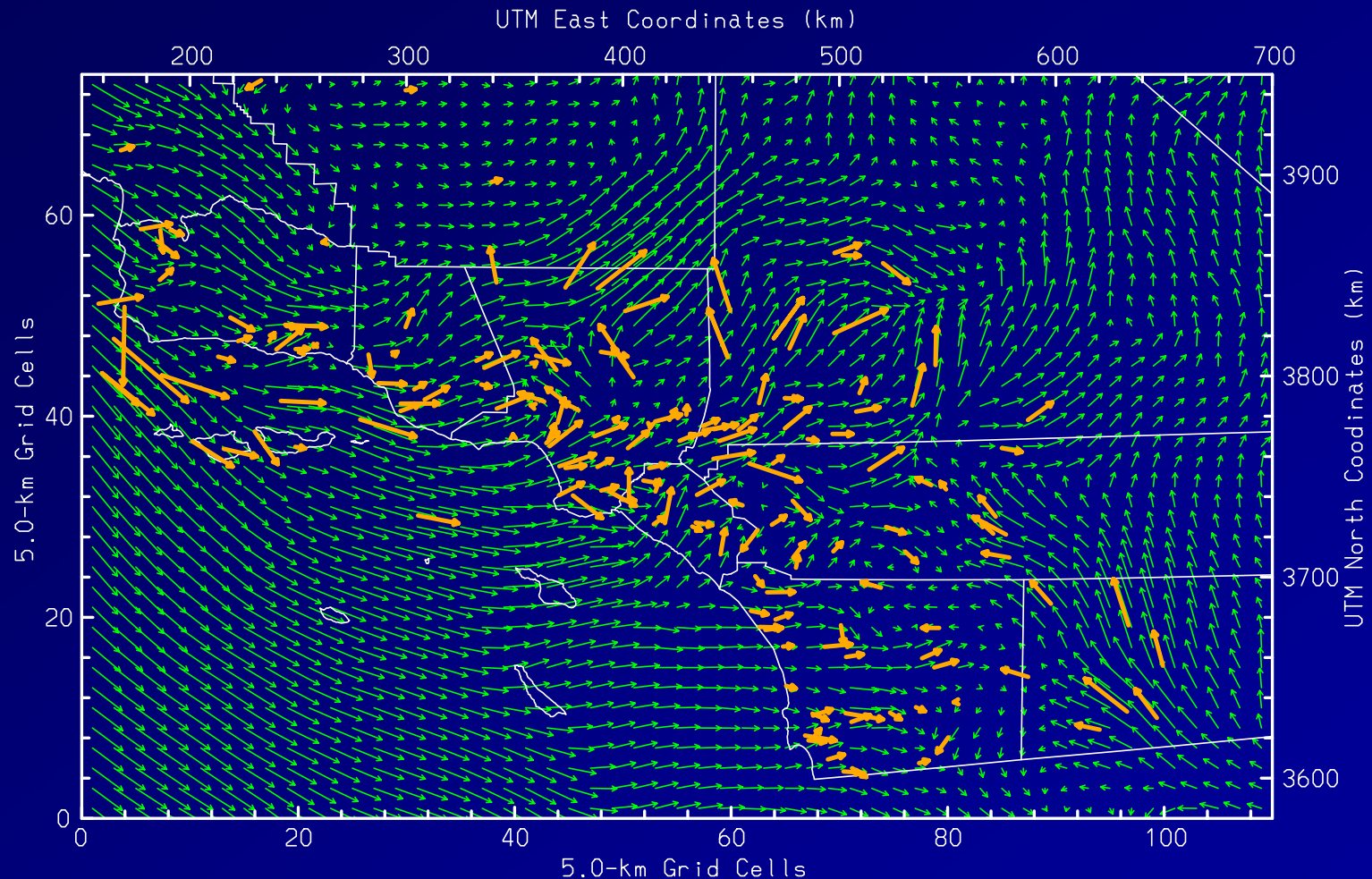
Upper-Air Site Data Validation Plot Example



Upper-Air Multiple Site Data Validation Plot Example



Model Wind Field with RWP Data

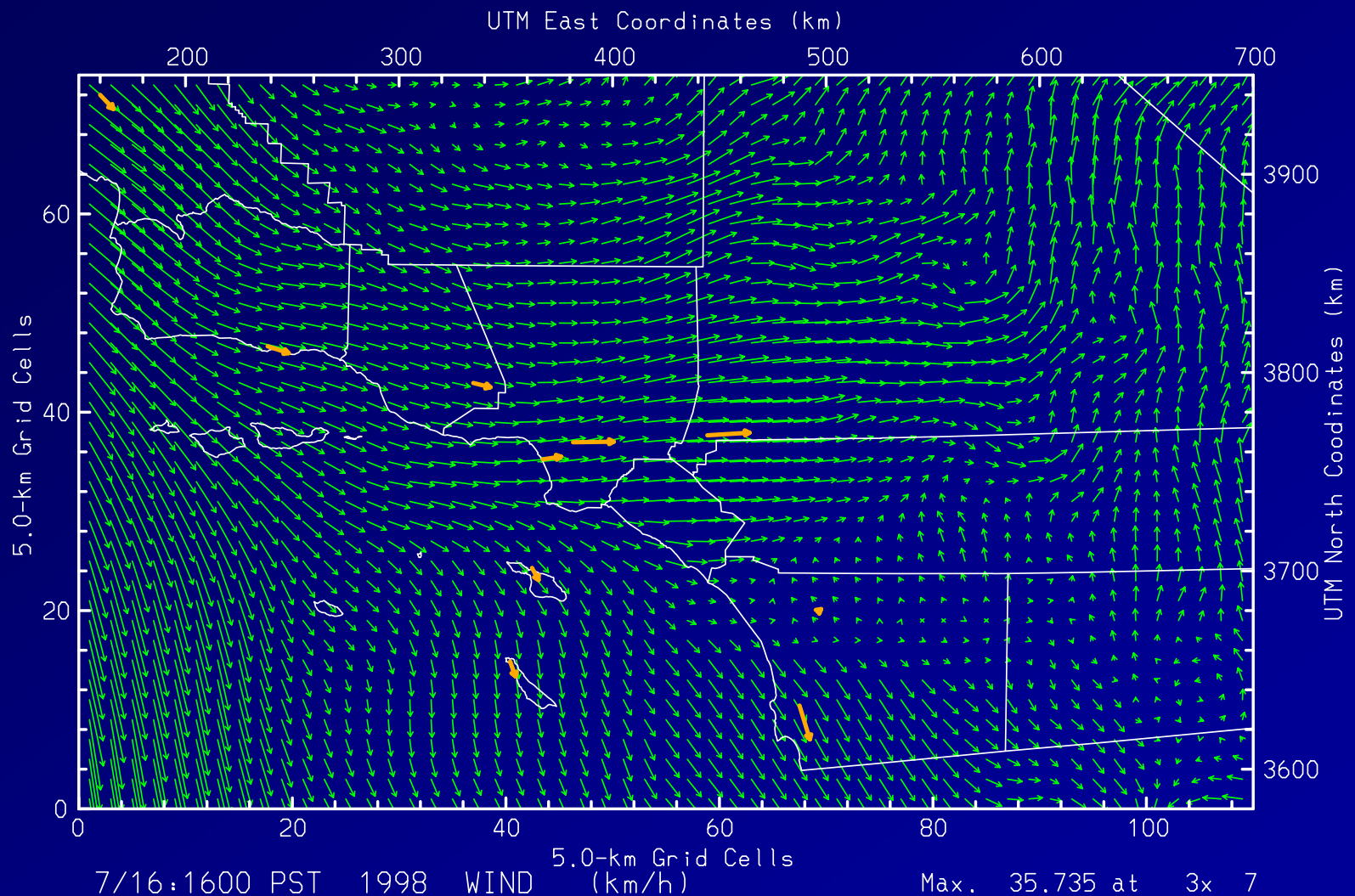


SCOS/CALMET -(Level 1:0-20m),selected stations, MM5 initial Guess

7/16:1600 hrs 1998 WIND (km/h)

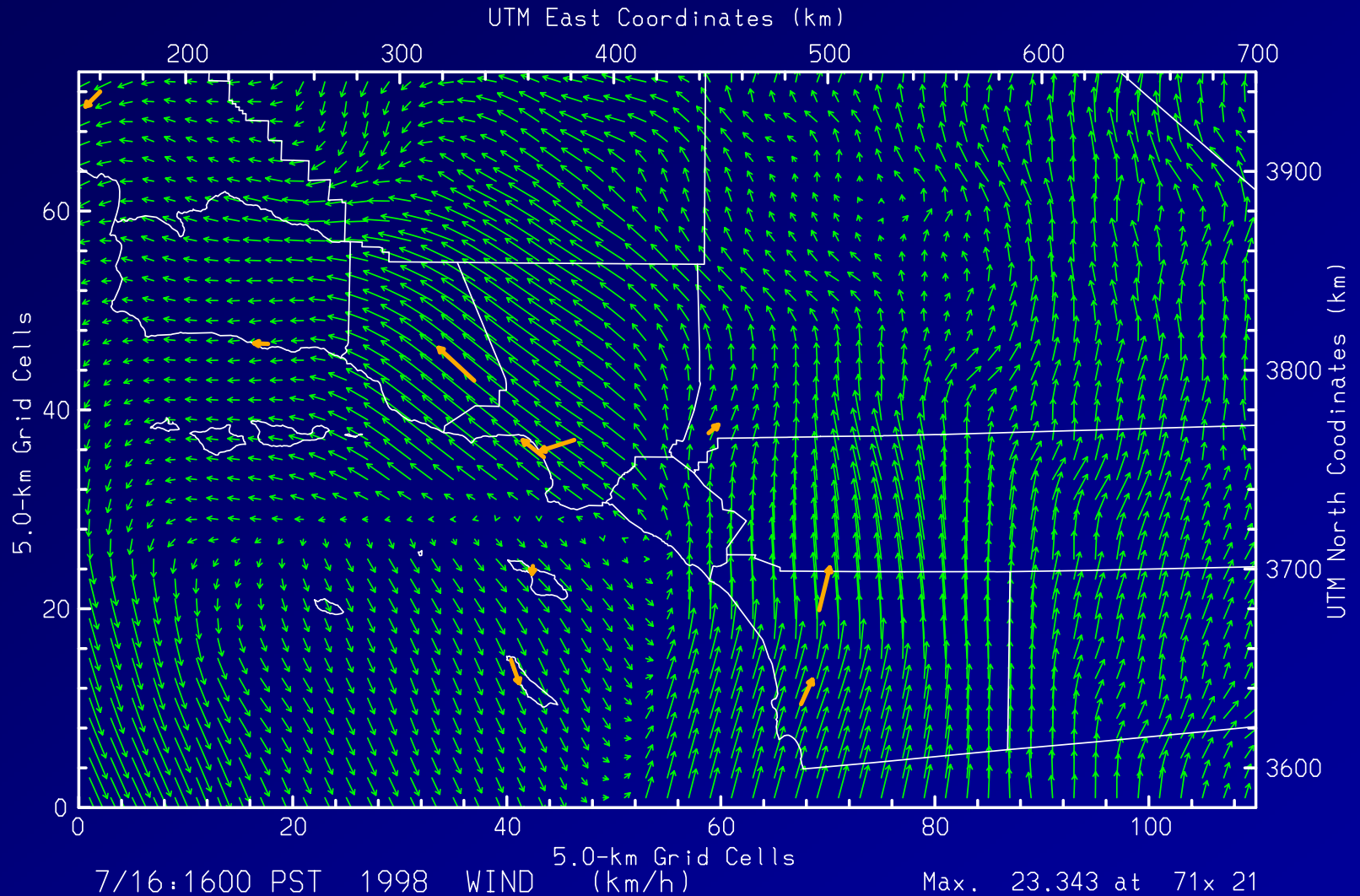
Max. 26.829 at 49x 53

Model Wind Field with RWP Data



CALMET/MM5 initial gues -(Level 7:400-600 m) selected STN

Model Wind Field with RWP Data



CALMET/MM5 Initial guess field -(Level 10:1000-1500 m) Selected STN

Some Regulatory Applications of Boundary Layer Profilers

- Air Quality Forecasting
- Air Quality Modeling
- Source Evaluations
- Field Programs & Case Analyses
- Other Environmental Efforts
- Regulatory Compliance & Violation Evaluation
 - UA data used to support monitoring studies for smoke, dust, odor & emissions limit compliance
- Permit Processes
 - Source Modeling Evaluations
 - New Source Review & PSD
- Source Apportionment
 - Trajectory analysis
- UA data used to help define boundaries for Air Toxics Reporting

Source Evaluations

- Sodars widely used for:
 - stack/plume analysis
 - mixing depth detail
- MiniSodars used for:
 - street-level traffic emissions studies
 - detailed shallow mixed layer analyses
 - prescribed & wildland fire impact analysis
- Profilers now being used for
 - Transportation emission impact studies
 - long-range transport analyses
 - e.g., power plant plume studies

Some Regulatory Applications of Boundary Layer Profilers

- Air Quality Forecasting
 - Air Quality Modeling
 - Source Evaluations
 - ➔ Field Programs & Case Analyses
 - Other Environmental Efforts
- ➔ Support of Local, Regional & National air monitoring programs
 - Ongoing, e.g., PAMS
 - Intensive field monitoring to support research & model development
 - Regulatory Compliance Analyses
 - ➔ Natural Event Evaluation & Documentation
 - e.g., volcanic activity, wildfires, high winds

Field Programs

Temporary Profiler Applications

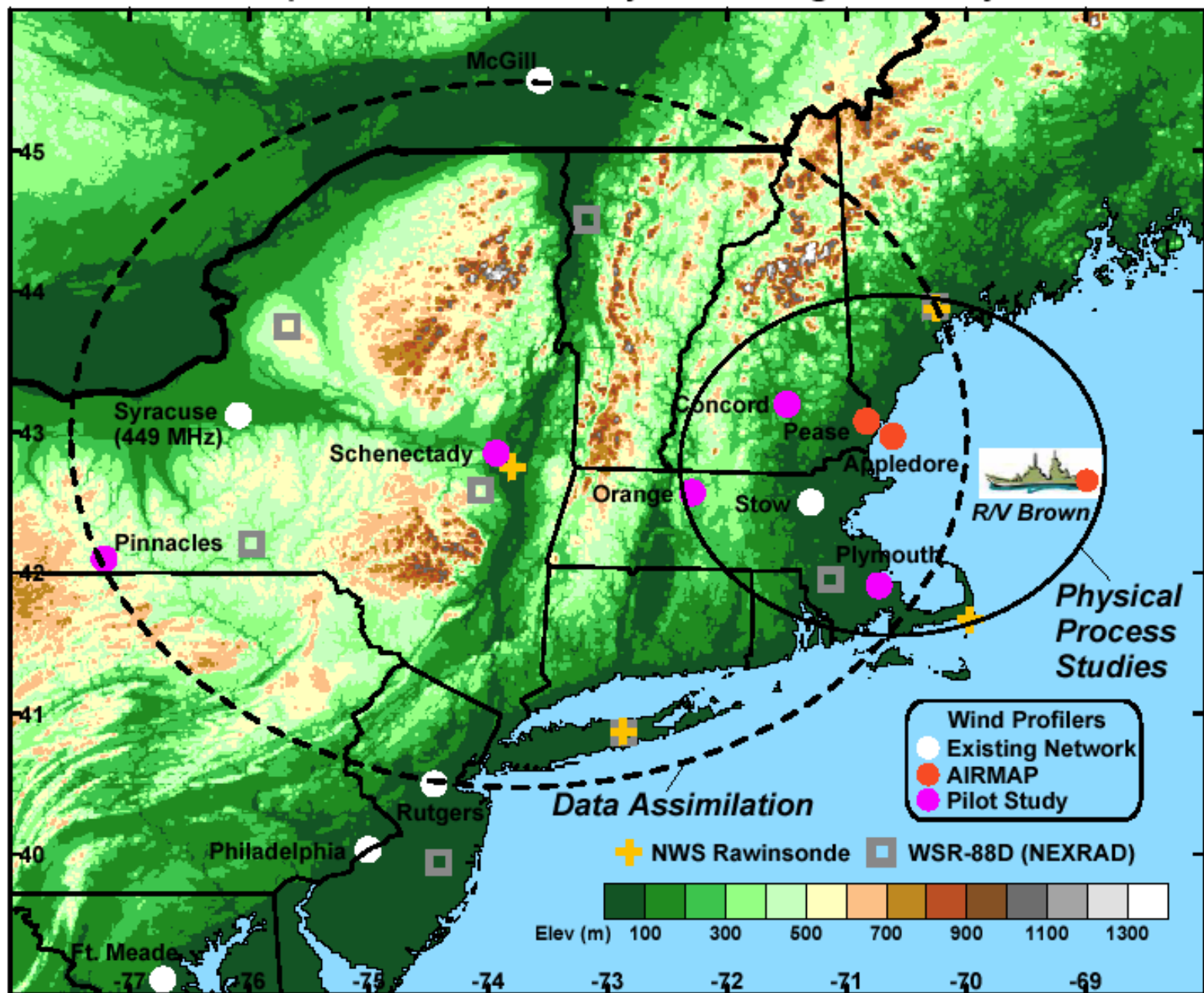
■ Small Field Studies

- e.g., Lynwood Carbon Monoxide Study used sodars to evaluate morning mixing and transport under strong radiation inversions

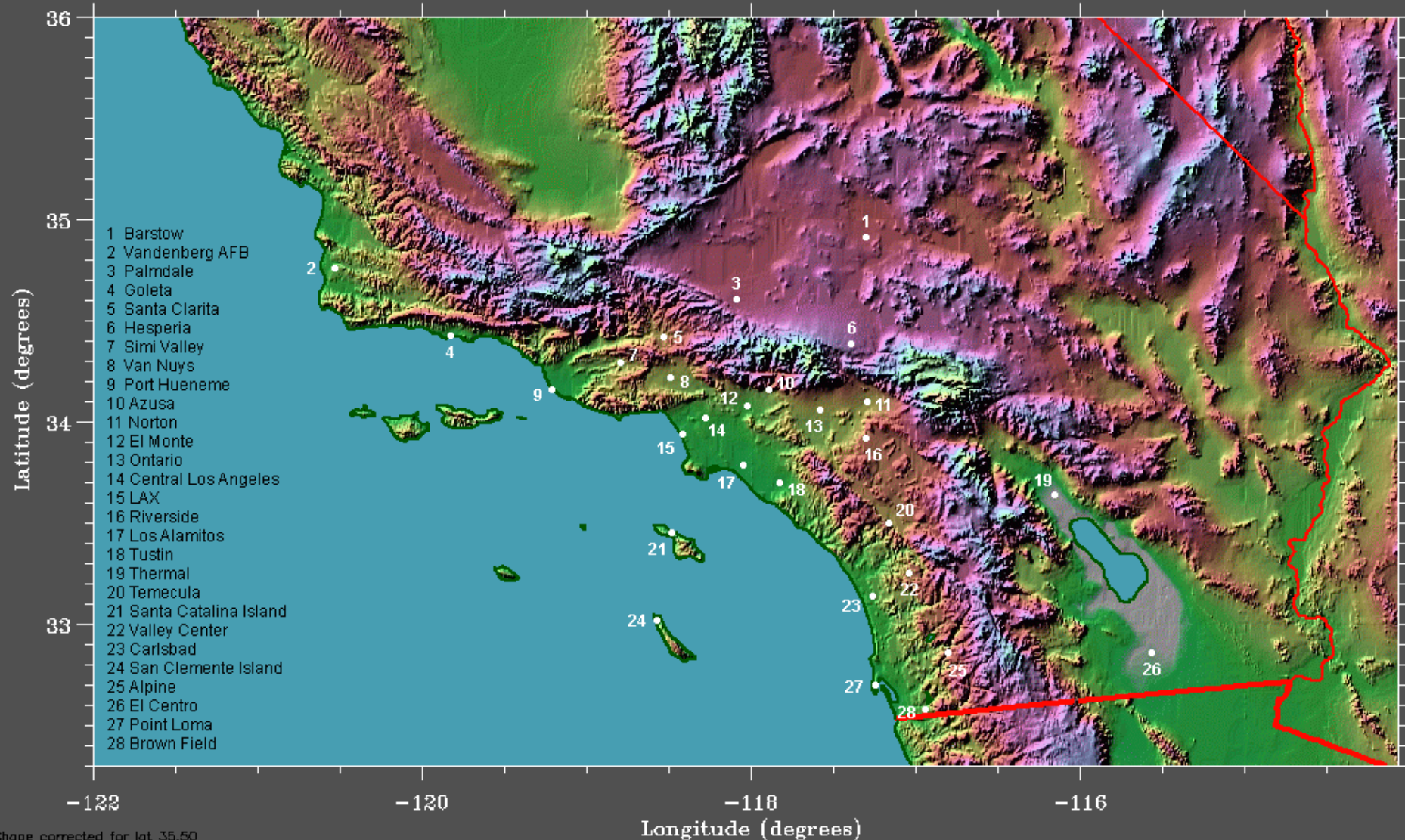
■ Large Field Programs

- Cooperation between government agencies, university groups and private sector is critical
 - Southern California Ozone Study 1997 (SCOS97-NARSTO)
 - <http://www.arb.ca.gov/research/scos/scos.htm>
 - NARSTO NE
 - Lake Michigan Ozone Study (LMOS)
 - New England Air Quality Study (NEAQS) 2002
 - <http://www.al.noaa.gov/NEAQS/>
 - Central California Ozone Study (CCOS)
 - <http://www.arb.ca.gov/airways/ccos/ccos.htm>

Profiler Network for AIRMAP and the New England Temperature and Air Quality Forecasting Pilot Study



SCOS97-NARSTO Upper Air Sites



Some Regulatory Applications of Boundary Layer Profilers

- Air Quality Forecasting
- Air Quality Modeling
- Source Evaluations
- Field Programs & Case Analyses

→ Other Environmental Efforts

→ Emergency Planning & Response

- Natural disaster, fire, nuclear & toxics

→ Burn Management

- Wildland fire response
- Prescribed burns
- Agricultural burns

→ Energy Management

- power generation planning
- repair weather support
- wind power turbine optimization

→ Acid Deposition & Regional Haze Studies

Airshed Modeling Issues with RWP/RASS Data

→ Data Management Issues

- Mixing Height Issues
- Data Gap to Lowest Range Gates
- Vertical Velocity Issues
- Moisture Profile Measurements

→ Format inconsistencies from different instrumentation and data sources

→ Inconsistent data validation practices

→ Data validation process is time consuming (expensive)

→ More validation steps can be automated and graphics tool incorporated

Airshed Modeling Issues with RWP/RASS Data

- Data Management Issues

- Mixing Height Issues

- Height Coverage Issues

- Vertical Velocity Issues

- Moisture Profile Measurements

- Developing good mixing height analysis fields are labor intensive (expensive)

- Mixing heights derived from refractive index parameter (CN^2) are valuable, but

- Model analysis fields subject to inaccuracies due to terrain, missing data, sea-breeze interaction, differential heating across analysis domain, etc.

Airshed Modeling Issues with RWP/RASS Data

- Data Management Issues
- Mixing Height Issues
- Height Coverage Issues
- Vertical Velocity Issues
- Moisture Profile Measurements

- Height coverage often limited by atmospheric conditions, interference
 - Can estimate with nearby soundings
- Data Gap to Lowest Range Gates (~120m AGL)
 - Winds within shallow mixed layer are critical to air quality models
 - Can fill with additional met towers and sodars, when available
 - Typically must interpolate

Airshed Modeling Issues with RWP/RASS Data

- Data Management Issues
 - Mixing Height Issues
 - Height Coverage Issues
 - Vertical Velocity Issues
 - Moisture Profile Measurements
- Important to understand the atmospheric processes
 - Not clear if vertical velocity correction should be used with RASS temperatures
 - corrected T_v often does not pass through the averaging criteria
 - Corrected T_v often appears over-corrected

Airshed Modeling Issues with RWP/RASS Data

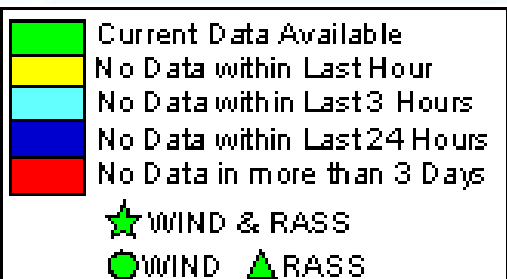
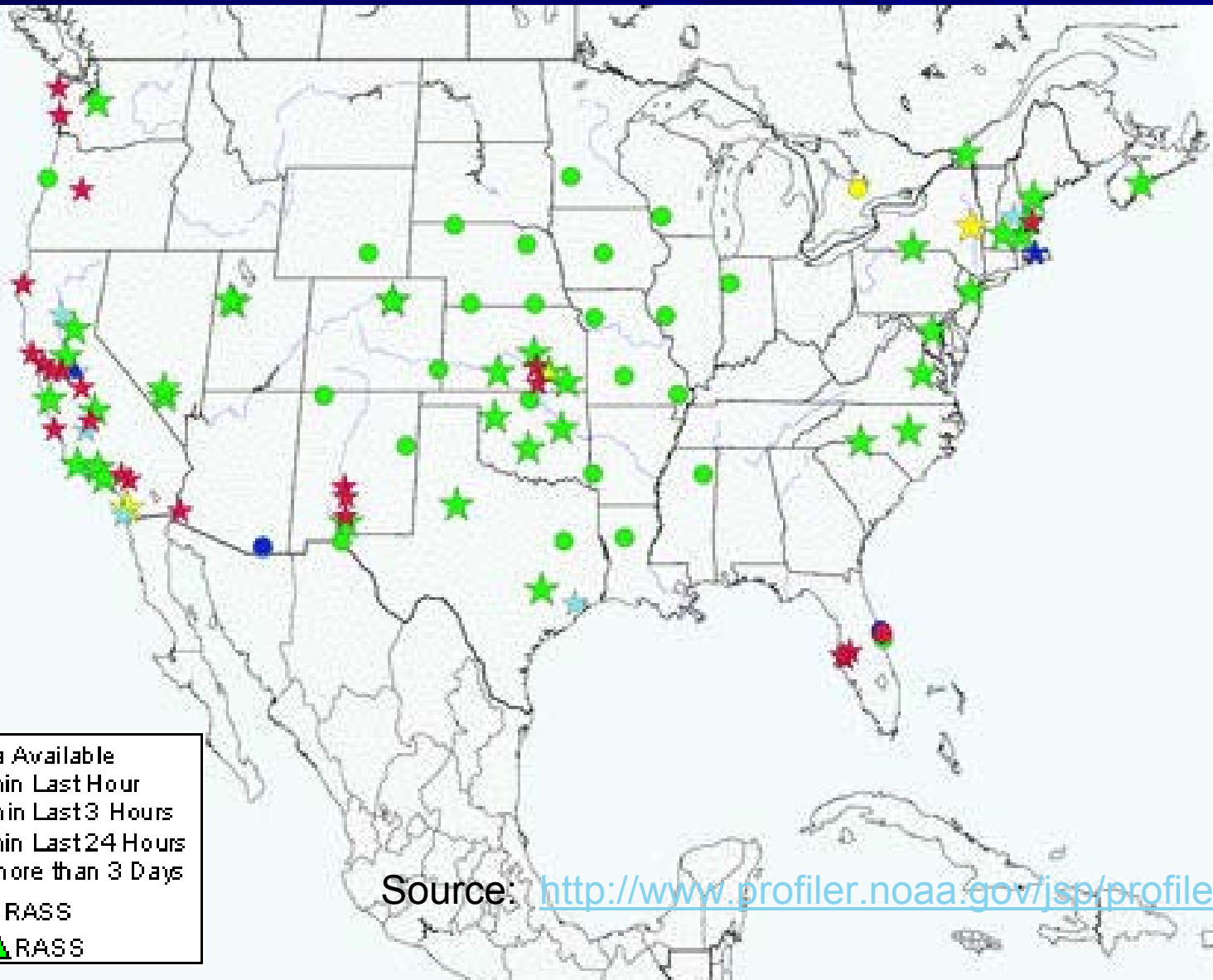
- Data Management Issues
 - Especially important for aerosol modeling
- Mixing Height Issues
 - Used for conversion of virtual temperature data (T_v to T fields)
- Height Coverage Issues
- Vertical Velocity Issues
 - Can use mixing height field with surface humidity field to estimate 3-D humidity field
- Moisture Profile Measurements

Upper Air Data Recommendations

(based on [Main & Roberts, 2001](#))

- Continue UA Measurements & Increase Use of Data
- Prepare Support Information & Procedures
 - list of profilers, locations, operating agencies, hardware, software, operating periods, standard operating procedures (SOPs), contact names, data archive location, & remote access directions
- Develop Regional (or Network) Standardized Approach
 - to data validation, data access & analysis tool development
- Develop a Data Repository
 - Work with EPA to develop a national data repository
 - US EPA Air Information Retrieval System (AIRS) ???
 - NOAA – FSL ???
 - Otherwise, create regional UA database
 - for easier archiving, access & dissemination
 - with data reporting deadlines

NOAA Forecast Systems Laboratory Multi-Agency Profiler Graphical Data Display

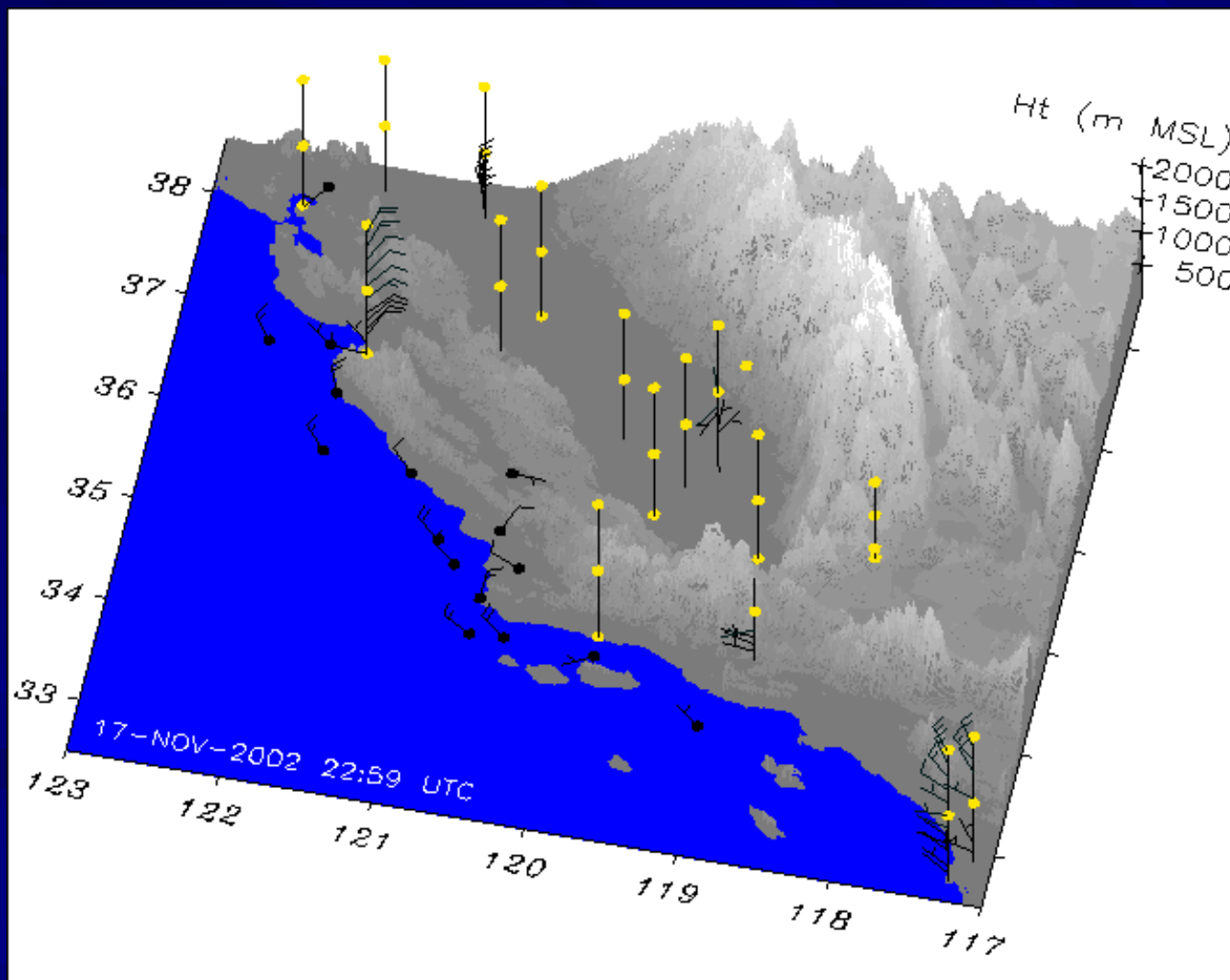


Source: <http://www.profiler.noaa.gov/jsp/profiler.jsp>

Coastal Wind Profiler Page

Source: Dick Lind, Naval Postgraduate School, Monterey, CA

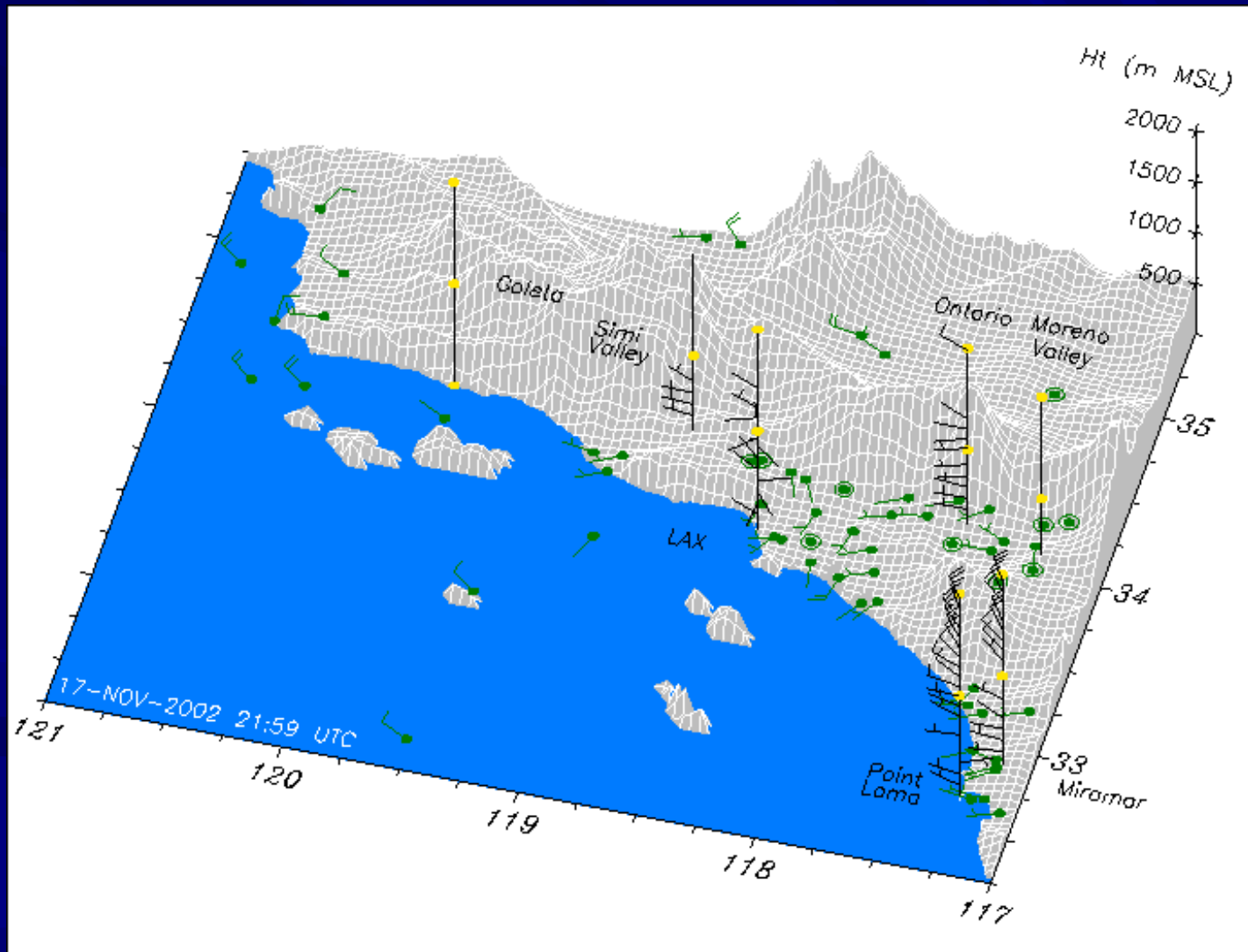
<http://www.weather.nps.navy.mil/profiler/coastprof.html>



Profiler & Coastal Winds for Southern California

Source: Dick Lind, Naval Postgraduate School, Monterey, CA

<http://www.weather.nps.navy.mil/profiler/coastprof.html>



Upper Air Data Recommendations

(continued)

- Integrate Surface Met, Sodar & RWP/RASS Data
- Archive Both Consensus Averaged and Moments Data from RWP/RASS
 - Consensus data good for near-real-time use and most applications
 - Moments data can be post-processed to retrieve data where consensus averaging is ineffective
 - Boundary layer info may be best retrieved from moments
- Use Workgroups and Other Forums
 - to share data analysis results and techniques
 - expand outside the air quality community
- Increase UA network where needed
- Consider year-round UA data collection
 - to support PM_{2.5} & other pollutant programs

Summary of Drawbacks

of Boundary Layer Profiling for Air Quality Applications

- Instrument Cost
 - Initial Purchase & Maintenance
- Siting can be Difficult
 - RWP frequency considerations, Sodar & RASS noise, interference, site availability, permitting, ...
- Vertical coverage is dependent upon atmospheric conditions
 - i.e., poor data coverage in dry/stable air due to strong temperature inversion, stagnant conditions, desert locations, etc.
 - measurements in such conditions are often important for air quality interests
- Data quality control can be laborious & time consuming (costly)
- Few air quality agencies have staff dedicated to upper air measurements
- “It’s a helluvah lot of data!”

Summary of Benefits of Boundary Layer Profiling for Air Quality Applications

- Require Less Manpower & Expendables
 - compared to balloon-borne soundings
 - Can operate, optimize and collect data remotely via modem, internet, satellite link
- Continuous, Automated
- Reduce need to predict Intensive Operational Periods (IOPs) during field programs
 - Allow for continuous measurements
- Can get near-real-time data feedback for field study operational decisions and public notification of pending air quality events

References

Profiler Application Guidance for Air Quality

■ EPA Meteorological Measurements:

- EPA Vol. IV (mainly surface met & sodars) (US EPA, 1995a)
- EPA Photochemical Modeling Guidance (US EPA, 2000)

■ EPA Photochemical Assessment Monitoring Stations (PAMS) Program

- EPA PAMS Analysis Guidance (US EPA, 1994b, 1995b, 1996, 1997)
- EPA PAMS Implementation Manual (US EPA, 1994a)
- EPA Technical Assistance Document for the Sampling and Analysis of Ozone Precursors (EPA/600-R-98-161, Sept. 1998)

- <http://www.epa.gov/ttn/amtic/files/ambient/pams/newtad.pdf>

- Section 6: Guidance for PAMS Meteorological Monitoring

- Section 6.5: Upper Air Meteorological Monitoring

- Little on Radar Wind Profilers/RASS Measurements

- CFR Title 40, Chapter I, Part 58, Appendix D, Section 4: Network Design for Photochemical Assessment Monitoring Stations (PAMS)

- <http://www.access.gpo.gov/nara/cfr/cfr-table-search.html>

References

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